OIPE JC10 JAN 20 2004 PATENT & TRADEMARK OFFICE

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AF/2828 /B/

In re application of	:	Fermann
Appl. No.	:	09/785,944
Filed	:	February 16, 2001
For	:	MODE-LOCKED MULTI-MODE FIBER LASER PULSE SOURCE
Examiner	:	Jeffrey Zahn
Art Unit	:	2828

I hereby certify that this correspondence and all marked attachments are being deposited with the United States Postal Service as first-class mail in an envelope addressed to: Mail Stop Appeal Brief - Patents, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450, on

January 16, 2004
(Date)

James B. Bear, Reg. No. 25,221

Mail Stop Appeal Brief - Patents
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

Transmitted herewith in triplicate is an Appellants' Brief to the Board of Patent Appeals:

(X) Fee for filing brief in the amount of $330 is enclosed, along with a fee for a one (1) month extension of time to respond.

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PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	:	Martin E. Fermann	) Group Art Unit 2828
Appl. No.	:	09/785,944	)
Filed	:	February 16, 2001	)
For	:	MODE-LOCKED, MULTI-MODE FIBER LASER PULSE SOURCE	)
Examiner	:	Jeffrey Zahn	)

<u>ON APPEAL TO THE BOARD OF PATENT APPEALS AND INTERFERENCES</u>
<u>APPLICANT'S BRIEF</u>

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

This appeal brief is filed in triplicate. A check in the amount of $440 is included to cover the fee for filing the appeal brief pursuant to 35 C.F.R. 1.17(f). Please charge any additional fees which may be required to Deposit Account No. 11-1410.

<u>STATEMENT OF INTEREST</u>

Pursuant to 37 C.F.R. 1.192(c)(1), Applicants hereby notify the Board of Patent Appeals and Interferences that IMRA AMERICA, INC., 1044 Woodridge Avenue, Ann Arbor, Michigan 48105, is the real party of interest.

<u>REQUEST FOR CONSOLIDATED ORAL HEARING</u>

Applicant petitions the Board of Appeals and Interferences to consolidate the appeal hearings for Application No. 09/738,372, Application No. 09/738,373, Application No. 09/785944 and Application No. 09/262662. All four of these applications share a common inventor, Martin E. Fermann, and all four are assigned to the real party of interest in this case,

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namely IMRA AMERICA, INC. All four applications relate to lasers and methods for using lasers, and all four are pending before the same examination group and the same primary examiner, Paul Ip, in the Patent Office. Consolidating these appeals for the oral hearing will conserve the time of the Board and will reduce the cost for the Assignee.

STATUS OF THE CLAIMS AND AMENDMENTS

Claims 1-50 and 55-58 are pending and are the subject of this appeal. Claims 1-19, 22-50 and 55-58 stand rejected, while Claims 20 and 21 have been objected to as depending from a rejected claim.

These Claims were the subject of a non-final rejection mailed on August 29, 2003. All of these claims, except Claims 20 and 21, have been rejected at least twice as required by 35 U.S.C. § 134. In fact, most of these claims have been the subject of five non-final rejections.

In the first rejection, dated 7/31/01, the Examiner mistakenly rejected the claims based on double patenting, though the duplicate claims had been cancelled in a preliminary amendment.

In each of the second, third, fourth and fifth rejections, the claims were rejected as obvious in view of a combination of Fermann et al. 5,627,848 with a secondary reference.

In the second rejection, dated 4/24/02, the secondary reference (Stock et. al) was not prior art because it was filed later than the present application. Moreover, the Examiner acknowledged at page 7 of the second rejection that "Fermann [U.S. 5,627,848] discloses the claimed invention except for the multi-mode optical fiber doped with a gain medium and positioned along said cavity axis...."

The third rejection, dated 11/06/02, was a copy of the second rejection, except that a new secondary reference was used (Harter et al. 6,034,975) and the Examiner removed the admission that Fermann et al. fails to disclose multi-mode optical fiber doped with a gain medium. Thereafter, Applicant's counsel interviewed the Examiner on 1/13/03. During the interview, the Examiner's supervising primary agreed that the claims were acceptable, as to form, except that claim 55 and its dependent claims should define the steps as occurring in a laser cavity. Applicant filed an amendment on 10/16/03 making the required change to claim 55. In that Amendment, the Examiner was reminded that the Fermann et al. patent fails to disclose doped

multi-mode optical fiber, and that Harter discloses single mode, not multi-mode doped fiber. In addition, the Applicant argued that Harter is not prior art to the present application.

In the fourth rejection, dated 3/31/2003, the Examiner again copied the rejection originally issued in the second rejection on 4/24/02, this time substituting yet another secondary reference (Tatham 5,861,970) in combination with Fermann. Neither of these references discloses a laser having doped multi-mode fiber which amplifies light confined to the fundamental mode of the fiber. In fact, Fermann never mentions multi-mode fiber. To the contrary, the fiber 101 referred to in the Examiner's rejection, is single mode fiber, as described specifically at Col. 4, lines 19-40. The specification of a core diameter of 6 microns, with a numerical aperture of 0.16, for the fiber specified, clearly identifies single mode fiber.

The combining reference, Tatham (5,861,970) does not disclose a doped multi-mode fiber. To the contrary, Tatham discloses in the Background section, at Col. 1, lines 12 -36, the reasons for not using multi-mode fiber. Other than this section of the Tatham patent, no mention is made of multi-mode fiber.

In the most recent rejection, the Examiner has combined Fermann with yet another reference, Mears et al. (4,787,927). Except for the amendment mentioned above to Claim 55, the claims of this application have not changed since the filing on February 16, 2001.

SUMMARY OF THE INVENTION

Both actively mode-locked lasers and passively mode-locked lasers are well known in the laser art. For example, compact mode-locked lasers have been formed as ultrashort pulse sources using single-mode rare-earth-doped fibers. One particularly useful fiber pulse source is based on Kerr-type passive mode-locking. Such pulse sources have been assembled using widely available standard fiber components to provide pulses at the bandwidth limit of rare-earth fiber lasers with MegaHertz repetition rates.

The peak-power of pulses from mode-locked single-mode lasers has been limited by the small fiber core size that has been employed to ensure single-mode operation of the fiber. For a standard mode-locked single-mode erbium fiber laser operating at 1.55 μm with a core diameter of 10 μm and a round-trip cavity length of 2 m, corresponding to a pulse repetition rate of 50 MHz, the maximum oscillating peak power is about 1 KW.

The present invention overcomes the foregoing difficulties associated with peak power limitations in mode-locked lasers, by providing a mode-locked multi-mode fiber laser which greatly exceeds the peak power limits of conventional mode-locked single-mode fiber lasers.

With this invention, a mode-locked fiber laser may be constructed to obtain, for example, 360 fsec near-bandwidth-limited pulses with an average power of 300 mW at a repetition rate of 66.7 MHz. The peak power of these exemplary pulses is estimated to be about 6 KW.

FIG. 1A illustrates the mode-locked laser cavity 11 of this invention which uses a length of multi-mode amplifying fiber 13 within the cavity to produce ultra-short, high-power optical pulses. As used herein, "ultra-short" means a pulse width below 100 ps. The fiber 13, in the example shown, is a 1.0 m length of non-birefringent $Yb^{3}+$ /$Er^{3}+$ -doped multi-mode fiber. Typically, a fiber is considered multi-mode when the V-value exceeds 2.41, i.e., when modes in addition to the fundamental mode can propagate in the optical fiber. In this example, the fiber 13 has a numerical aperture of 0.20 and a core diameter of 16 μm. The outside diameter of the cladding of the fiber 13 is 200 μm. The fiber 13 is coated with a low-index polymer producing a numerical aperture of 0.40 for the cladding. A 10 cm length of single-mode Corning Leaf fiber 15 is thermally tapered to produce a core diameter of approximately 14 μm to ensure an optimum operation as a mode filter, and this length is fusion spliced onto a first end 17 of the multi-mode fiber 13.

In this exemplary embodiment, the cavity 11 is formed between a first mirror 19 and a second mirror 21. It will be recognized that other cavity configurations for recirculating pulses are well known, and may be used. In this example, the mirrors 19, 21 define an optical axis 23 along which the cavity elements are aligned.

The cavity 11 further includes a pair of Faraday rotators 25, 27 to compensate for linear phase drifts between the polarization eigenmodes of the fiber, thereby assuring that the cavity remains environmentally stable. As referenced herein, the phrase "environmentally stable" refers to a pulse source which is substantially immune to a loss of pulse generation due to environmental influences such as temperature drifts and which is, at most, only slightly sensitive to pressure variations

A polarization beam-splitter 29 on the axis 23 of the cavity 11 ensures single-polarization operation of the cavity 11, and provides the output 30 from the cavity. A half-wave plate 31 and a

quarter-wave plate 33 are used to introduce linear phase delays within the cavity, providing polarization control to permit optimization of polarization evolution within the cavity 11 for mode-locking.

To induce mode-locking, the cavity 11 is formed as a Fabry-Perot cavity by including a saturable absorber 35 at the end of the cavity proximate the mirror 19. A two-photon absorber 39 is used as a nonlinear power limiter to protect the saturable absorber 35. The laser beam from the fiber 15 is collimated by a lens 43 and refocused, after rotation by the Faraday rotator 25, by a lens 45 onto the anti-reflection-coated surface 39 of the two-photon absorber 37. Other focusing lenses 47 and 49 in the cavity 11 aid in better imaging the laser signal onto the multi-mode fiber 13.

Light from a Pump light source 51 is directed through a fiber bundle and injected into the end 53 of the multi-mode fiber 13 opposite the single-mode fiber 17. The pump light is coupled into the cavity 11 via a pump signal injector 55, such as a dichroic beam-splitter . Lenses 47 and 48 are optimized for coupling of the pump power from the fiber bundle 57 into the cladding of the multi-mode fiber 13.

Alternate embodiments of the invention are shown in Figs. 4, 5, 6, 8 and 11. In each case, the light in the laser cavity is confined to substantially the fundamental mode of the multi-mode amplifying optical fiber. In the example of Fig. 1, the tapered leaf fiber 15 operates as an optical guide to confine the light to substantially the fundamental mode. Figs. 9 and 10 show other mechanisms which may be used as optical guides for this purpose.

ISSUE PRESENTED ON APPEAL

Whether Claims 1-19, 22-50 and 55-58 define subject matter which is obvious under 35 U.S.C. §103 over Fermann et al. (5,627,848) in view of Mears et al. (4,787,927).

GROUPING OF THE CLAIMS

In Applicants' opinion, all of the claims should be grouped together for this appeal.

DISCUSSION OF THE REFERENCES RELIED UPON BY THE EXAMINER

THE FERMANN REFERENCE

The Fermann patent (U.S. 5,627,848) discloses a mode-locked fiber laser using a single mode optical fiber. In this respect, it discloses many of the elements of the claims in the present application. It does not, however, disclose the use of a multi-mode fiber, nor does it disclose

confining the light within the multi-mode fiber to preferentially the fundamental mode of the multi-mode fiber.

THE MEARS REFERENCE

The Mears et al. Patent (U.S. 4,787,925 discloses a method of making a preform for drawing doped optical fibers. More specifically, at Col. 3, lines 24 through 55, this patent discloses an embodiment of the invention for fabricating doped multi-mode optical fibbers. Moreover, the reference at Col 1, Lines 12-5 states that doped fibers made according to the invention are useful in manufacturing lasers. No description is provided regarding the form of laser contemplated.

ARGUMENT

Every apparatus claim pending here (Claims 1-50, 58) includes as one element a "multi-mode optical fiber" doped with a gain medium. Every method claim pending here (Claims 55-57) includes as one step "amplifying said light energy within said cavity in a multi-mode fiber." The Examiner states that

> "Fermann et al. Disclose a laser for generating ultra-short optical pulses (Fig. 1, 4-8), comprising: a cavity which repeatedly passes light energy along a cavity axis; a length of multi-mode optical fiber (See Fig. 1, Character 101) doped with a gain medium and positioned along said cavity axis; a pump (see Fig. 1, Character 103) for exciting said gain medium, the multi-mode optical fiber doped with a gain medium and positioned along said cavity axis (see Fig. 1, Character 104."

The cited Fermann reference, however, does not disclose multi-mode fiber. Rather, that reference discloses double-clad single-mode fiber, which is used to permit pumping by a diode laser array. This type of fiber is specifically described in the background section of the cited reference as follows:

> "To minimize cost, modelocked fiber lasers also should employ diode laser arrays. Indeed, it has been long known that continuous wave fiber lasers may be pumped by diode laser arrays when a doubleclad structure is employed in the fiber design. See, e.g., U.S. Pat. No. 4,815,079 to Snitzer et al. According to Snitzer et al., the fiber is designed to have two claddings, wherein the outer cladding has a low refractive index and the inner cladding has a significantly higher refractive index, giving a typical numerical aperture for light capture by the inner cladding between 0.20 and 0.60. The fiber core then has an even higher refractive index and is placed inside the inner cladding, such that the core location is significantly offset from the center of the inner cladding.

> "Snitzer et al. alternatively disclose the inner cladding as having a nearly rectangular shape. Both of these designs ensure that any light launched into the inner cladding crosses over the fiber core as often as possible, so that the light may be efficiently absorbed when the fiber core is doped with a rare-earth gain material. **The fiber core may then be designed to be single mode, and, as a result, a single-mode laser signal output may be obtained when the fiber is placed into a resonator**. Note, however, that perfectly acceptable performance from double-clad fibers having a centro-symmetric fiber structure, i.e., a fiber core placed in the center of the inner cladding, was recently demonstrated. H. Zelmer, U. Williamkowski, A Tunnerman and H. Welling, "High-power cw neodymium-doped double-clad fiber lasers", CLEO 95, paper CMB4. Such pumping schemes were previously predicted in U.S. Pat. No. 3,808,549 to Maurer. **The fiber design can then be reduced to that of a standard single-mode fiber with a low-index coating (such as silicone rubber)**, which, in fact, was the industry standard for fiber fabrication before the advent of acrylate coatings."
>
> U.S. Patent 5,627,848 at Col. 2, Ln. 18-51, emphasis added.

Please note that the fiber described in this portion of the background section is precisely the fiber that is described in the description of the preferred embodiment:

> "One preferable configuration of the fiber 101 includes Er^{3+} and Yb^{3+} doping levels of 800 ppm and 8000 ppm, respectively, in a phosphoaluminosilicate glass host. The core diameter of the fiber 101 is 6μm, with a numerical aperture (NA) of 0.16. The inner cladding has a diameter of 100 μm and is coated with silicon rubber to give the inner cladding an effective NA of 0.4"
>
> U.S. Patent 5,627,848 at Col. 4, Ln. 20-26.

Some confusion may have been introduced by the fact that the reference refers to a mode stripper 104 (see, for example, Col. 4 at ln. 57 and following). This mode stripper, however, is used to remove **cladding modes,** not core modes (see Col. 4, ln. 61-62), and does not suggest that the fiber itself is not a single mode fiber.

This distinction, is supported by the dictionary definitions which are attached to this amendment as Exhibit A. This exhibit was introduced into the file in the amendment filed February 16, 2001. Exhibit A includes copies from the "Fiber Optics Standard Dictionary, pages 614-615 (providing a definition for "multimode optical fiber") and pages 928-929 (providing a definition for "single-mode optical fiber"). The Board will note that these terms refer to the number of "bound" modes, also known as core modes, which the fiber will support. As can be seen from these definitions, in this art, "multi-mode optical fiber" refers to a fiber capable of

supporting multiple bound modes. Because the cited reference only refers to multiple cladding modes, and specifically refers to the fiber itself as "single mode," Applicant believes that the rejection of the pending claims is not supported.

A definition of whether a fiber is multi-mode or single mode is provided in the specification of this case at page 9, lines 8-10: "Typically a fiber is considered multi-mode when the V-value exceeds 2.41...". As described at Col. 4, lines 20-40 of the Fermann reference, the fiber described in the Fermann reference has a core diameter of 6μm and a numerical aperture (NA) of 0.16, while the signal has a wavelength of 1.56μm. Applicant has attached as Exhibit B a copy of U.S. Patent 6,496,301 which includes at Col. 6, Ln. 2 the classic formula for calculating the V-number of fiber: V=(.pi.d_{core} NA)/.lambda., where .lambda. is the wavelength in free space. In this case, pi=3.1416; d_{core} =6μm; NA=0.16 and lambda=1.56μm. Thus, the above formula yields a V-number for the Fermann fiber of 1.93. Since 1.93 is clearly less than 2.41, using the definition in the present application, the Fermann fiber is not multi-mode fiber.

Moreover, the Fermann reference simply makes no suggestion that a multi-mode fiber might be used for a mode-locked pulse laser.

Additionally, the apparatus claims require either "an optical guide positioned on said cavity axis which confines the light amplified by said multi-mode optical fiber to preferentially the fundamental mode of said multi-mode optical fiber" or "means for confining the optical energy amplified by said multi-mode optical fiber to substantially the fundamental mode of said multi-mode optical fiber." Similarly, all of the method claims include a step of "confining said light energy within said laser cavity substantially to the fundamental mode of said multi-mode fiber". No such element or step is suggested by Fermann.

The Examiner attempts to supply this last element by the combination of the Mears patent, stating"

> "The Fermann discloses the claimed invention except for an optical guide positioned on cavity axis which confines the light amplified by said multi-mode optical fiber to preferentially the fundamental mode of said multi-mode fiber, the multi-mode fiber and multi mode filter fiber are tapered at said fusion spliced, and the pump is couple to said multi-mode fiber along said cavity axis. It would have been obvious at the time of applicant's invention, to combine Mears et al of teaching a multi-mode optical fiber doped with a gain medium and positioned along said cavity axis with a laser for

> generating ultra-short optical pulse because if the optical communications system employs multi-mode fiber, each of the different modes will have a different group velocity, thus modulated signals, i.e. pulses of light passing down the multi-mode optical fiber, which are made up of a number of different modes of the waveguide will experience a different group delay from each of their modes. This causes a pulse formed from more than one mode to spread out as it propagates, and is called intermodal dispersion. Once consecutive pulses have spread out so that they are no longer distinguishable, one from the other, the information transmission limit of the optical communications system has been reached. This limit is expressed as a bandwidth distance product since it will be reached at a higher bit rate for a shorter optical communications link. Intermodal dispersion between the modes of multi-mode fibers is one of the reasons why modern optical communications systems have moved to the use of single mode optical fiber which, since it only supports one optical mode, does not suffer from intermodal dispersion. ..."

It is not clear what this statement means. What is clear is that Mears does disclose multi-mode fiber and its manufacture, but does not suggest its use in a mode-locked fiber laser. Certainly, there is no suggestion in Mears that the light within a multi-mode fiber might be limited to substantially the fundamental mode of that fiber, or that an optical guide should be used for this purpose. Simply stated, Mears discloses multi-mode fiber, and nothing more.

In summary, Fermann fails to disclose multi-mode fiber and also fails to disclose the limitation of light to the fundamental mode of that fiber. The Examiner even acknowledges in the rejection the latter deficiency. Mears does nothing to suggest that light within the multi-mode fiber laser be limited substantially to the fundamental mode of the multi-mode fiber.

REQUEST FOR ORAL HEARING

Applicant hereby requests an Oral Hearing in this Appeal.

CONCLUSION

Applicants submit that the claims of this application are allowable.

Respectfully submitted,

KNOBBE, MARTENS, OLSON & BEAR, LLP

Dated: 1/16/04

By:

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APPENDIX

CLAIMS ON APPEAL

1. (Original) A laser for generating ultra-short optical pulses, comprising:

a cavity which repeatedly passes light energy along a cavity axis;

a length of multi-mode optical fiber doped with a gain medium and positioned along said cavity axis;

a pump for exciting said gain medium;

a mode locking mechanism positioned on said cavity axis; and

an optical guide positioned on said cavity axis which confines the light amplified by said multi-mode optical fiber to preferentially the fundamental mode of said multi-mode optical fiber.

2. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said mode locking mechanism comprises a passive mode locking element.

3. (Original) A laser for generating ultra-short optical pulses as defined in Claim 2 wherein said passive mode locking element comprises a saturable absorber.

4. (Original) A laser for generating ultra-short optical pulses as defined in Claim 3 wherein said saturable absorber comprises InGaAsP.

5. (Original) A laser for generating ultra-short optical pulses as defined in Claim 3 additionally comprising a power limiter for protecting said saturable absorber.

6. (Original) A laser for generating ultra-short optical pulses as defined in Claim 5 wherein said power limiter comprises a two photon absorber.

7. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said optical guide comprises a single-mode mode-filter fiber on said cavity axis.

8. (Original) A laser for generating ultra-short optical pulses as defined in Claim 7 wherein said single-mode mode-filter fiber is fusion spliced onto one end of said multi-mode optical fiber.

9. (Original) A laser for generating ultra-short optical pulses as defined in Claim 8 wherein said multi-mode fiber is tapered at said fusion splice.

10. (Original) A laser for generating ultra-short optical pulses as defined in Claim 8 wherein said single-mode mode-filter fiber is tapered at said fusion splice.

11. (Original) A laser for generating ultra-short optical pulses as defined in Claim 8 wherein both said single-mode mode-filter fiber and said multi-mode fiber are tapered at said fusion splice.

12. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said pump is coupled to said multi-mode fiber along said cavity axis.

13. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said pump is coupled to the side of said multi-mode fiber.

14. (Original) A laser for generating ultra-short optical pulses as defined in Claim 13 additionally comprising an optical coupler for coupling said pump to said multi-mode fiber.

15. (Original) A laser for generating ultra-short optical pulses as defined in Claim 13 additionally comprising a v-groove on said multi-mode optical fiber for coupling said pump to said multi-mode fiber.

16. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 additionally comprising a polarization beam splitter for outputting said ultra-short optical pulses from said laser.

17. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said cavity comprises a pair of reflectors at its opposite ends.

18. (Original) A laser for generating ultra-short optical pulses as defined in Claim 17 wherein one of said pair of reflectors is partially reflecting and provides the output for said cavity.

19. (Original) A laser for generating ultra-short optical pulses as defined in Claim 17 wherein said mode locking mechanism comprises a saturable absorber, and wherein one of said reflectors is formed on a surface of said saturable absorber.

20. (Original) A laser for generating ultra-short optical pulses as defined in Claim 19 wherein said mode locking mechanism additionally comprises a power limiter for protecting said saturable absorber, and wherein said saturable absorber is formed on a surface of said power limiter opposite said one of said reflectors.

21. (Original) A laser for generating ultra-short optical pulses as defined in Claim 20 wherein said power limiter comprises a two-photon absorber.

22. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 additionally comprising a linear phase drift compensator on said cavity axis.

23. (Original) A laser for generating ultra-short optical pulses as defined in Claim 22 wherein said linear phase drift compensator comprises a Faraday rotator.

24. (Original) A laser for generating ultra-short optical pulses as defined in Claim 23 wherein said linear phase drift compensator comprises a pair of Faraday rotators.

25. (Original) A laser for generating ultra-short optical pulses as defined in Claim 22 additionally comprising a linear polarization transformer on said cavity axis.

26. (Original) A laser for generating ultra-short optical pulses as defined in Claim 25 wherein said linear polarization transformer comprises a wave plate.

27. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said mode locking mechanism comprises an active mode locking element.

28. (Original) A laser for generating ultra-short optical pulses as defined in Claim 27 wherein said active mode locking element comprises an optical amplitude modulator.

29. (Original) A laser for generating ultra-short optical pulses as defined in Claim 27 wherein said active mode locking element comprises an optical frequency modulator.

30. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said ultra-short optical pulses preferentially in the fundamental mode of said multi-mode optical fiber have a pulse width below 500 psec.

31. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 additionally comprising an environmental stabilizer on said cavity axis to assure that said cavity remains environmentally stable.

32. (Original) A laser for generating ultra-short optical pulses as defined in Claim 31 wherein said environmental stabilizer comprises a Faraday rotator.

33. (Original) A laser for generating ultra-short optical pulses as defined in Claim 32 wherein said environmental stabilizer comprises a pair of Faraday rotators.

34. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said optical guide comprises an optical fiber doped with an amplifying medium to provide gain guiding.

35. (Original) A laser for generating ultra-short optical pulses as defined in Claim 34 wherein said amplifying medium is concentrated centrally within a fraction of the core diameter of said optical fiber.

36. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said optical guide comprises a single-mode optical fiber on said cavity axis.

37. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said optical guide comprises a mode-filter on said cavity axis.

38. (Original) A laser for generating ultra-short optical pulses as defined in Claim 37 wherein said mode filter excites the fundamental mode of said multi-mode fiber.

39. (Original) A laser for generating ultra-short optical pulses as defined in Claim 38 wherein said mode filter excites the fundamental mode of said multi-mode fiber with an efficiency of at least 90%.

40. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said cavity additionally comprises a positive dispersion element.

41. (Original) A laser for generating ultra-short optical pulses as defined in Claim 40 wherein said positive dispersion element comprises a length of single-mode positive dispersion fiber positioned along said cavity axis.

42. (Original) A laser for generating ultra-short optical pulses as defined in Claim 41 additionally comprising an output coupler for limiting the light energy at said single-mode positive dispersion fiber to less than 10% of the peak power in said cavity.

43. (Original) A laser for generating ultra-short optical pulses as defined in Claim 42 additionally comprising a frequency converter for compressing pulses generated by said cavity.

44. (Original) A laser for generating ultra-short optical pulses as defined in Claim 43 wherein said frequency converter comprises a frequency doubler.

45. (Original) A laser for generating ultra-short optical pulses as defined in Claim 44 wherein said frequency doubler comprises chirped periodically poled $LiNbO_3$.

46. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said multi-mode fiber includes a core, and wherein said gain medium in said multi-mode optical fiber is concentrated centrally within the core of said multi-mode fiber.

47. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said multi-mode optical fiber is polarization-maintaining.

48. (Original) A laser for generating ultra-short optical pulses as defined in Claim 47 wherein said polarization-maintaining multi-mode fiber has an elliptical core.

49. (Original) A laser for generating ultra-short optical pulses as defined in Claim 47 wherein said polarization maintaining multi-mode fiber comprises stress-producing regions.

50. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said cavity additionally comprises a fiber grating written onto said multi-mode fiber, said grating primarily reflecting the fundamental mode of said multi-mode fiber.

51. (Canceled)

52. (Canceled)

53. (Canceled)

54. (Canceled)

55. (Previously Presented) A method of generating ultra-short optical pulses, comprising:

circulating light energy within a laser cavity;

amplifying said light energy within said laser cavity in a multi-mode fiber; and

confining said light energy within said laser cavity substantially to the fundamental mode of said multi-mode fiber.

56. (Original) A method of generating ultra-short optical pulses as defined in Claim 55 additionally comprising mode locking said light energy.

57. (Original) A method of generating ultra-short optical pulses as defined in Claim 55 wherein said confining comprises mode filtering said light energy.

58. (Original) A mode-locked laser for generating high power ultra-short optical pulses, comprising:

A multi-mode optical fiber doped with gain material for amplifying optical energy;

means for pumping said optical fiber; and

means for confining the optical energy amplified by said multi-mode optical fiber to substantially the fundamental mode of said multi-mode optical fiber.

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Fiber Optics Standard Dictionary

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transmission system, interface, optical interface, optical signal, propagation medium, radio, signal, sound signal, telegraph, telephone, transmission system, video, voice.

multimegabit data service: A data service that provides a data signaling rate (DSR) that is over 1 Mb • s^{-1} (Mb/s, megabits per second). *Note:* A fiber optic link has the capability to provide multimegabit data services. *See* **switched multimegabit data service.** *See also* **data signaling rate, fiber optic link, telecommunications service.**

multimeter: A test instrument that (a) is used for measuring voltages, currents, and resistances that may lie within a number of different ranges, (b) has a range selection capability to obtain measurement precision, and (c) must be operated with caution so as not to allow the indicator to go off scale. A measurement should be made starting with the scale that measures the largest unit. *Note:* A lightwave multimeter manufactured by the Hewlett-Packard Company that has two slots for plug-in modules with sensitivities from −70 dBm to −110 dBm and a wavelength range from 450 nm to 1700 nm (0.45 µm to 1.7 µm). *Synonyms* **volt-ohm meter, volt-ohm milliammeter.** *See* **digital multimeter, electronic multimeter, optical multimeter.** *See also* **current, precision, range, scale, voltage.** *Refer to* **Fig. L-8.**

multimode: In an electromagnetic wave propagating in a waveguide, such as a lightwave propagating in an optical fiber, pertaining to (a) the existence of two or more modes in the wave or (b) the capability of the waveguide to support two or more modes. *See also* **electromagnetic wave, lightwave, mode, optical fiber, propagation, single mode, waveguide.** *Refer to* **Figs. O-1, T-6.**

multimode dispersion: 1. *Synonym* **multimode distortion. 2.** *See* **optical multimode dispersion.**

multimode distortion: In an optical waveguide, such as an optical fiber, a slab dielectric waveguide, or optical integrated circuit (OIC), the distortion that (a) results from differential mode delay, (b) is a result of the spread in time of a pulse because the velocity of propagation is not the same for all the modes in an optical pulse, i.e., optical signal, and (c) is not a result of dispersive mechanisms, i.e., is not a form of dispersion, such as waveguide dispersion, profile dispersion, or material dispersion. *Note 1:* Multimode distortion in multimode step-index optical fibers may be compared to multipath propagation of radio signals. The direct signal is distorted by the arrival of the reflected signals a moment later. In a step-index optical fiber, rays taking more direct paths through the fiber core, i.e., those undergoing fewer reflections at the core-cladding boundary, traverse the length of the fiber sooner than those rays that undergo more reflections, resulting in signal distortion at the end of the fiber. *Note 2:* Multimode distortion limits the bandwidth of a given multimode optical fiber. A typical step index optical fiber with a 50-µm (micron) core would be limited to about 20 MHz (megahertz) for a 1-km (kilometer) length, i.e., a bandwidth • distance factor of 20 MHz • km. *Note 3:* Multimode distortion may be considerably reduced, but not completely eliminated, by the use of a core having a graded refractive index profile. The bandwidth • distance factor of a typical off-the-shelf graded index multimode optical fiber having a 50-µm (micron) core may be over 1 GHz • km (gigahertz • kilometer), with over 10 GHz • km fibers having been produced. *Note 4:* Because of its similarity to dispersion in its effect on optical signals, multimode distortion is sometimes incorrectly referred to as "intermodal dispersion," "modal dispersion," or "multimode dispersion." Such usage is incorrect because multimode distortion is not truly a dispersive effect. Dispersion is a wavelength-dependent phenomenon, particularly because of the spectral width of a pulse, whereas multimode distortion may occur to a single wavelength. *Synonyms* **intermodal distortion, modal distortion, multimode dispersion.** *See also* **bandwidth • distance factor, cladding, coherence area, coherence length, coherence time, core, differential mode delay, distortion, distortion-limited operation, fiber optics, graded refractive index, material dispersion, mode, multimode optical fiber, multipath, optical pulse, optical signal, optical waveguide, profile dispersion, propagation, spectral width, step index optical fiber, waveguide dispersion, wavelength.**

multimode facility: In communications systems, a facility that is capable of handling more than one transmission mode, such as telephone, telegraph, radio, and facsimile transmission. *See also* **facility, facsimile, radio, telegraph, telephone, transmission mode.**

multimode fiber: *Synonym* **multimode optical fiber.**

multimode group delay: *Synonym* **differential mode delay.**

multimode group delay spread: In an electromagnetic wave propagating in a waveguide, such as an optical pulse propagating in an optical fiber, the variation in group delay time, caused by differences in group velocity, among bound propagating modes even at a single frequency. *Note:* The differences in arrival times of the leading and trailing edges of a pulse at the end of the waveguide, as compared to the sending end, is caused by the different propagation delays of the different modes. The modes can be considered as different opti-

cal paths of different optical path lengths. In an optical fiber, it is possible for photons or waves that propagate along the optical fiber axis of the core to arrive at the end sooner than those that follow a helical path through the core, thus causing the pulse duration at the end of the fiber to be increased. If the pulse duration is too great, intersymbol interference, i.e., an overlapping of consecutive pulses, will occur. The duration of the received pulse can be reduced if the refractive index profile of the core is arranged so that light rays taking a helical path along the outer edges of the core propagate through a lower-refractive-index material, hence travel faster in the longer path than axial rays propagating along the optical axis, or in a helical path closer to the axis of the core, in the higher refractive index material, so that they arrive at the end of the fiber at the same time. Actual propagation delay is of little consequence, as long as all rays of a given pulse arrive at the end of the fiber at the same time. Zero-dispersion optical fibers are being made. *Synonym* **differential mode delay.** *See also* **bound mode, core, electromagnetic wave, group delay time, group velocity, intersymbol interference, leading edge, mode, optical fiber, optical fiber axis, optical path length, optical pulse, path, photon, propagation, propagation delay, pulse duration, ray, refractive index profile, trailing edge, wave, zero dispersion, zero-dispersion optical fiber.**

multimode laser: A laser that emits radiation containing two or more modes, i.e., two or more different central wavelengths. *See also* **central wavelength, laser, multiline laser, radiation.**

multimode operation: In analog systems, the use of a common circuit or a single propagation medium for both analog and digital data, such as voice, binary coded data, facsimile, and international Morse code all on one circuit though not necessarily at the same time. *Note:* Simultaneous transmission in more than one transmission mode at the same time can be accomplished using multiplexing techniques. Fiber optic nets, fiber optic links, and fiber optic loops can support multimode operation. *See also* **analog data, circuit, digital data, facsimile, fiber optic link, fiber optic loop, fiber optic net, international Morse code, mode, multiplexing, propagation medium, transmission mode, voice.**

multimode optical fiber: An optical fiber that supports the propagation of more than one bound mode at a given operating wavelength. *Note 1:* A multimode optical fiber may be either a graded index (GI) optical fiber or a step index (SI) optical fiber. *Note 2:* The number of modes that an optical fiber will support depends on the core diameter, the numerical aperture (NA), and the wavelength. *Synonym* **multimode fiber.** *See also* **bound mode, cladding mode, core, core diameter, coupled modes, fiber optics, graded index optical fiber, modal distribution, modal noise, mode, mode scrambler, mode volume, numerical aperture, optical fiber, single-mode optical fiber, step index optical fiber, wavelength.** *Refer to* **Figs. A-6, L-11, R-7.** *Refer to* **Appendix B, Tables 2, 4.**

multimode waveguide: A waveguide that can support more than one mode. *Note:* Because different wavelengths constitute different modes and the number of modes is also dependent on the numerical aperture (NA) and the core diameter, a given "multimode" waveguide might support only one mode and therefore could be called a single-mode waveguide if the operating wavelength is long enough, and conversely, a given "single-mode waveguide" might support several modes and therefore could be called a multimode waveguide if the operating wavelength is short enough. *See also* **core, core diameter, mode, numerical aperture, single-mode waveguide, wavelength.**

multinode network: A communications network, such as a fiber optic net, in which users may be interconnected through more than one node. *See also* **fiber optic net, network, node.**

multipaired cable: A paired cable that has two or more pairs of electrical conductors, such as two or more twisted pairs. *See also* **cable, conductor, fiber optic cable, hybrid cable, paired cable, twisted pair.**

multipath: 1. For lightwaves in dielectric waveguides, pertaining to the different paths taken by the various modes in lightwaves propagating in the waveguide. *Note:* Causes of multipath in optical fibers include refractive index and entrance condition variations. **2.** The propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. *Note 1:* For radio, video, and microwave transmissions, causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from terrestrial objects, such as mountains and buildings. *Note 2:* Multipath can cause constructive interference, phase shifting, and destructive interference. *Note 3:* In facsimile and television transmission, multipath causes jitter and ghost images. *See also* **antenna, capture effect, constructive interference, destructive interference, dielectric waveguide, entrance condition, facsimile, ghost image, ionosphere, jitter, lightwave, mode, object, phase, phase shift, propagation, Rayleigh fading, reflection, refraction, refractive index, television, waveguide.**

multipath fading: In the propagation of electromagnetic waves, including (a) radio waves in free space and the atmosphere and (b) lightwaves in dielectric waveguides, such as optical fibers, slab dielectric wave-

single harmonic distortion: In a signal, the ratio of (a) the power of a given harmonic, such as the second, third, or fourth harmonic, to (b) the power of the fundamental frequency, i.e., the first harmonic. *Note:* Single harmonic distortion is measured at the output of a device under specified conditions and usually is expressed in dB. *See also* **distortion, frequency, fundamental frequency, harmonic distortion, signal, total harmonic distortion.**

single heterojunction: In a laser diode, a junction that (a) performs two energy level shifts and two refractive index shifts and (b) provides increased confinement of radiation direction, improved control of radiative recombination, and reduced nonradiative (thermal) recombination. *See also* **energy level, junction, laser diode, nonradiative recombination, radiation, radiative recombination.**

single inline package: An integrated circuit package that (a) has a rectangular housing, (b) has one row of pins on a side, and (c) is compatible with standard integrated circuit sockets. *Common abbreviation:* **SIP.** *Note:* An example of a dual inline package (DIP) is a microcircuit package with one row of seven vertical leads that is specially designed for mounting on a printed circuit board. The SIP is used to contain control circuits for controlling fiber optic links and fiber optic nets. *See also* **circuit, dual inline package, fiber optic link, fiber optic net, integrated circuit, large-scale integrated circuit, optical integrated circuit, single inline package switch.**

single lens: A lens composed of only one piece of optical material, such as glass or plastic. *See also* **compound lens, glass, optical glass, optical plastic.**

single mode: **1.** In an electromagnetic wave propagating in a waveguide, such as a lightwave propagating in an optical fiber, pertaining to (a) the existence of one and only one mode in the wave or (b) the capability of the waveguide to support one and only one. **2.** In an electromagnetic wave, such as a lightwave or radio wave, propagating in a waveguide, such as an optical fiber, a hollow or dielectric-filled rectangular metallic waveguide, a slab dielectric waveguide, or an optical integrated circuit (OIC), pertaining to an operating condition in which only one propagation mode, i.e., a beam of only one wavelength, is supported by the waveguide because (a) the wavelength is at the cutoff wavelength, (b) shorter wavelengths could be supported but they are not in the incident wave, i.e., in the wave inserted into the guide, and (c) longer wavelengths cannot be supported even if they are in the incident waves, i.e., they do not fit in the cross section of the guide. *Note 1:* The concept of single mode is also applicable to sound waves in a length of tubing and to vibrations in material media. *Note 2:* An optical fiber designated as a single-mode fiber can support more than one mode by inserting lightwaves of shorter wavelength. Thus, for single-mode operation of a given fiber, the operating wavelength must be specified. *Note 3:* The single mode usually is the lowest order bound mode, consisting of a pair of orthogonally polarized electric and magnetic fields. *See also* **cutoff wavelength, electric field, electromagnetic wave, incident, lightwave, lowest order mode, low-order mode, magnetic field, mode, multimode optical fiber, operating wavelength, optical fiber, optical integrated circuit, orthogonal, polarization, polarized mode, propagation, propagation medium, radio wave, single-mode optical fiber, slab dielectric waveguide, waveguide.** *Refer to* **Figs. O-1, S-20, T-6.**

single-mode fiber: *Synonym* **single-mode optical fiber.**

single-mode launching: The insertion of an electromagnetic wave into a waveguide in such a manner that (a) only one propagation mode is coupled into, and hence transmitted, by the guide, (b) various parameters, such as incidence angle, beam diameter, skew ray angle, and source to waveguide longitudinal displacement are controlled, and (c) propagation of the mode depends on waveguide dimensions, the wavelength of the inserted waves, and refractive indices of the material constituting the guide. *See also* **coupling, electromagnetic wave, incidence angle, mode, parameter, propagation, refractive index, skew ray, transmission, waveguide.**

single-mode optical fiber: An optical fiber in which only one bound mode, i.e., the lowest order bound mode, can propagate at a given wavelength, numerical aperture, and core radius. *Note 1:* The lowest order bound mode may be a pair of orthogonally polarized electric and magnetic fields. *Note 2:* To support one mode, the core radius must be less than twice the wavelength of the source of radiation and the numerical aperture must be adjusted accordingly. *Note 3:* In step index optical fibers, single-mode operation occurs when the normalized frequency, V, is less than 2.405. For power law profiles, single-mode operation occurs for a normalized frequency, V, less than approximately $2.405[(g + 2)/g]^{1/2}$, where g is the profile parameter. *Note 4:* If appropriate conditions are met, the orthogonal polarizations will not be associated with degenerate modes. *Synonyms* **monomode fiber, monomode optical fiber, single-mode fiber.** *See* **dispersion-unshifted single-mode optical fiber.** *See also* **bound mode, core, core diameter, mode, multimode optical fiber, normalized frequency, numerical aperture, operating**

mode, optical fiber, profile parameter, radiation, source, step index optical fiber. *Refer to* **Figs. E-1, L-11, M-3, R-7, S-9.**

single-mode optical waveguide: An optical waveguide that is capable of supporting the propagation of only one mode at a given wavelength. *Note:* An optical waveguide designed to operate in single mode at a given wavelength may support more than one mode if operated at shorter wavelengths. *See also* **mode, multimode, operating wavelength, optical waveguide, propagation, single mode, single-mode optical fiber, wavelength.**

single-mode waveguide: 1. A waveguide that can support only one mode. *Note:* Because different wavelengths constitute different modes and the number of modes is also dependent on the numerical aperture (NA) and the core diameter, a given multimode waveguide might support only one mode in a given wavelength range and therefore could be called a "single-mode waveguide" if the operating wavelength is long enough, and conversely, a given single-mode waveguide might support several modes and therefore could be called a multimode waveguide if the operating wavelength is short enough. **2.** A waveguide in which only one bound mode, i.e., the lowest order bound mode, can propagate at a given wavelength, numerical aperture, and cross-sectional dimension. *Note 1:* The lowest order bound mode may be a pair of orthogonally polarized electric and magnetic fields. *Note 2:* To support one mode, the cross-sectional dimension must be less than twice the wavelength of the source of radiation and the numerical aperture must be adjusted accordingly. *Note 3:* If appropriate conditions are met, the orthogonal polarizations will not be associated with degenerate modes. *Synonym* **monomode waveguide.** *See also* **bound mode, core, electric field, magnetic field, mode, multimode waveguide, numerical aperture, operating mode, orthogonal, polarization, radiation, range, single-mode optical fiber, source, waveguide, wavelength.**

single-node network: *See* **network topology.**

single optical fiber: An optical fiber that is optically isolated from other optical fibers but may be combined with other optical fibers to form fiber optic cables, aligned bundles, unaligned bundles, and fiber optic faceplates. *See also* **aligned bundle, fiber optic cable, fiber optic faceplate, optical fiber.**

single precedence message: A message in which (a) the same precedence is applicable to all addressees, i.e., to both action addressees and information addressees, and (b) only one precedence designator is needed. *See also* **dual precedence message, message, precedence, precedence designator.**

single sideband: Pertaining to amplitude modulation that (a) primarily is used in carrier telephony and high frequency (HF) radio to increase transmission efficiency, i.e., power efficiency, (b) is used to increase electromagnetic spectrum utilization in terms of the total number of channels available in a given bandwidth, (c) uses only one sideband for transmission while the other sideband and the carrier is suppressed, and (d) although proposed for the uplink and downlink of satellite systems, its use in satellite systems has been limited. *Common abbreviations:* **SS, SSB.** *See also* **amplitude modulation, bandwidth, carrier, channel, downlink, electromagnetic spectrum, satellite communications system, sideband, suppressed carrier, transmission efficiency, uplink.**

single sideband emission: An amplitude-modulated emission with only one sideband. *Common abbreviation:* **SSB emission.** *See also* **amplitude modulation, carrier, double sideband reduced carrier transmission, double sideband suppressed carrier transmission, double sideband transmission, emission, full carrier single sideband emission, reduced carrier single sideband emission, sideband, sideband transmission, suppressed carrier single sideband emission.**

single sideband equipment reference level: The power of one of two equal tones that, when used together to modulate a transmitter, cause it to develop its full rated peak power output. *Common abbreviation:* **SSB equipment reference level.** *See also* **level, peak power output, rated power output, reference, reference circuit, reference level, sideband transmission, transmitter.**

single sideband noise power ratio: The ratio of (a) the output power, measured with a notch in, to (b) the output power, measured with the notch out. *Note 1:* Measurements are made in which (a) notched noise is used, (b) power is in the notch bandwidth, and (c) power is measured at the output of the device for which the single sideband (SSB) noise power ratio is being determined. *Note 2:* The input power must be sufficient to maintain a constant total system mean noise power output. *See also* **noise, notch, notched noise.**

single sideband suppressed carrier (SSB-SC) transmission: Single sideband transmission in which (a) the carrier is suppressed and (b) the carrier power level is suppressed so that it is insufficient for signal demodulation. *Common abbreviation:* **SSB-SC transmission.** *See also* **carrier, demodulation, power level, single sideband transmission.**

single sideband transmission: Sideband transmission in which (a) only one sideband is transmitted and (b) the

IMRAA.015C1 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	:	Martin E. Fermann	Group Art Unit 2828
Appl. No.	:	09/785,944	
Filed	:	February 16, 2001	
For	:	MODE-LOCKED , MULTI-MODE FIBER LASER PULSE SOURCE	
Examiner	:	Jeffrey Zahn	

ON APPEAL TO THE BOARD OF PATENT APPEALS AND INTERFERENCES
APPLICANT'S BRIEF

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

This appeal brief is filed in triplicate. A check in the amount of $440 is included to cover the fee for filing the appeal brief pursuant to 35 C.F.R. 1.17(f). Please charge any additional fees which may be required to Deposit Account No. 11-1410.

STATEMENT OF INTEREST

Pursuant to 37 C.F.R. 1.192(c)(1), Applicants hereby notify the Board of Patent Appeals and Interferences that IMRA AMERICA, INC., 1044 Woodridge Avenue, Ann Arbor, Michigan 48105, is the real party of interest.

REQUEST FOR CONSOLIDATED ORAL HEARING

Applicant petitions the Board of Appeals and Interferences to consolidate the appeal hearings for Application No. 09/738,372, Application No. 09/738,373, Application No. 09/785944 and Application No. 09/262662. All four of these applications share a common inventor, Martin E. Fermann, and all four are assigned to the real party of interest in this case,

namely IMRA AMERICA, INC. All four applications relate to lasers and methods for using lasers, and all four are pending before the same examination group and the same primary examiner, Paul Ip, in the Patent Office. Consolidating these appeals for the oral hearing will conserve the time of the Board and will reduce the cost for the Assignee.

STATUS OF THE CLAIMS AND AMENDMENTS

Claims 1-50 and 55-58 are pending and are the subject of this appeal. Claims 1-19, 22-50 and 55-58 stand rejected, while Claims 20 and 21 have been objected to as depending from a rejected claim.

These Claims were the subject of a non-final rejection mailed on August 29, 2003. All of these claims, except Claims 20 and 21, have been rejected at least twice as required by 35 U.S.C. § 134. In fact, most of these claims have been the subject of five non-final rejections.

In the first rejection, dated 7/31/01, the Examiner mistakenly rejected the claims based on double patenting, though the duplicate claims had been cancelled in a preliminary amendment.

In each of the second, third, fourth and fifth rejections, the claims were rejected as obvious in view of a combination of Fermann et al. 5,627,848 with a secondary reference.

In the second rejection, dated 4/24/02, the secondary reference (Stock et. al) was not prior art because it was filed later than the present application. Moreover, the Examiner acknowledged at page 7 of the second rejection that "Fermann [U.S. 5,627,848] discloses the claimed invention except for the multi-mode optical fiber doped with a gain medium and positioned along said cavity axis...."

The third rejection, dated 11/06/02, was a copy of the second rejection, except that a new secondary reference was used (Harter et al. 6,034,975) and the Examiner removed the admission that Fermann et al. fails to disclose multi-mode optical fiber doped with a gain medium. Thereafter, Applicant's counsel interviewed the Examiner on 1/13/03. During the interview, the Examiner's supervising primary agreed that the claims were acceptable, as to form, except that claim 55 and its dependent claims should define the steps as occurring in a laser cavity. Applicant filed an amendment on 10/16/03 making the required change to claim 55. In that Amendment, the Examiner was reminded that the Fermann et al. patent fails to disclose doped

multi-mode optical fiber, and that Harter discloses single mode, not multi-mode doped fiber. In addition, the Applicant argued that Harter is not prior art to the present application.

In the fourth rejection, dated 3/31/2003, the Examiner again copied the rejection originally issued in the second rejection on 4/24/02, this time substituting yet another secondary reference (Tatham 5,861,970) in combination with Fermann. Neither of these references discloses a laser having doped multi-mode fiber which amplifies light confined to the fundamental mode of the fiber. In fact, Fermann never mentions multi-mode fiber. To the contrary, the fiber 101 referred to in the Examiner's rejection, is single mode fiber, as described specifically at Col. 4, lines 19-40. The specification of a core diameter of 6 microns, with a numerical aperture of 0.16, for the fiber specified, clearly identifies single mode fiber.

The combining reference, Tatham (5,861,970) does not disclose a doped multi-mode fiber. To the contrary, Tatham discloses in the Background section, at Col. 1, lines 12 -36, the reasons for not using multi-mode fiber. Other than this section of the Tatham patent, no mention is made of multi-mode fiber.

In the most recent rejection, the Examiner has combined Fermann with yet another reference, Mears et al. (4,787,927). Except for the amendment mentioned above to Claim 55, the claims of this application have not changed since the filing on February 16, 2001.

SUMMARY OF THE INVENTION

Both actively mode-locked lasers and passively mode-locked lasers are well known in the laser art. For example, compact mode-locked lasers have been formed as ultrashort pulse sources using single-mode rare-earth-doped fibers. One particularly useful fiber pulse source is based on Kerr-type passive mode-locking. Such pulse sources have been assembled using widely available standard fiber components to provide pulses at the bandwidth limit of rare-earth fiber lasers with MegaHertz repetition rates.

The peak-power of pulses from mode-locked single-mode lasers has been limited by the small fiber core size that has been employed to ensure single-mode operation of the fiber. For a standard mode-locked single-mode erbium fiber laser operating at 1.55 μm with a core diameter of 10 μm and a round-trip cavity length of 2 m, corresponding to a pulse repetition rate of 50 MHz, the maximum oscillating peak power is about 1 KW.

The present invention overcomes the foregoing difficulties associated with peak power limitations in mode-locked lasers, by providing a mode-locked multi-mode fiber laser which greatly exceeds the peak power limits of conventional mode-locked single-mode fiber lasers.

With this invention, a mode-locked fiber laser may be constructed to obtain, for example, 360 fsec near-bandwidth-limited pulses with an average power of 300 mW at a repetition rate of 66.7 MHz. The peak power of these exemplary pulses is estimated to be about 6 KW.

FIG. 1A illustrates the mode-locked laser cavity 11 of this invention which uses a length of multi-mode amplifying fiber 13 within the cavity to produce ultra-short, high-power optical pulses. As used herein, "ultra-short" means a pulse width below 100 ps. The fiber 13, in the example shown, is a 1.0 m length of non-birefringent Yb^3+ /Er^3+ -doped multi-mode fiber. Typically, a fiber is considered multi-mode when the V-value exceeds 2.41, i.e., when modes in addition to the fundamental mode can propagate in the optical fiber. In this example, the fiber 13 has a numerical aperture of 0.20 and a core diameter of 16 μm. The outside diameter of the cladding of the fiber 13 is 200 μm. The fiber 13 is coated with a low-index polymer producing a numerical aperture of 0.40 for the cladding. A 10 cm length of single-mode Corning Leaf fiber 15 is thermally tapered to produce a core diameter of approximately 14 μm to ensure an optimum operation as a mode filter, and this length is fusion spliced onto a first end 17 of the multi-mode fiber 13.

In this exemplary embodiment, the cavity 11 is formed between a first mirror 19 and a second mirror 21. It will be recognized that other cavity configurations for recirculating pulses are well known, and may be used. In this example, the mirrors 19, 21 define an optical axis 23 along which the cavity elements are aligned.

The cavity 11 further includes a pair of Faraday rotators 25, 27 to compensate for linear phase drifts between the polarization eigenmodes of the fiber, thereby assuring that the cavity remains environmentally stable. As referenced herein, the phrase "environmentally stable" refers to a pulse source which is substantially immune to a loss of pulse generation due to environmental influences such as temperature drifts and which is, at most, only slightly sensitive to pressure variations

A polarization beam-splitter 29 on the axis 23 of the cavity 11 ensures single-polarization operation of the cavity 11, and provides the output 30 from the cavity. A half-wave plate 31 and a

quarter-wave plate 33 are used to introduce linear phase delays within the cavity, providing polarization control to permit optimization of polarization evolution within the cavity 11 for mode-locking.

To induce mode-locking, the cavity 11 is formed as a Fabry-Perot cavity by including a saturable absorber 35 at the end of the cavity proximate the mirror 19. A two-photon absorber 39 is used as a nonlinear power limiter to protect the saturable absorber 35. The laser beam from the fiber 15 is collimated by a lens 43 and refocused, after rotation by the Faraday rotator 25, by a lens 45 onto the anti-reflection-coated surface 39 of the two-photon absorber 37. Other focusing lenses 47 and 49 in the cavity 11 aid in better imaging the laser signal onto the multi-mode fiber 13.

Light from a Pump light source 51 is directed through a fiber bundle and injected into the end 53 of the multi-mode fiber 13 opposite the single-mode fiber 17. The pump light is coupled into the cavity 11 via a pump signal injector 55, such as a dichroic beam-splitter . Lenses 47 and 48 are optimized for coupling of the pump power from the fiber bundle 57 into the cladding of the multi-mode fiber 13.

Alternate embodiments of the invention are shown in Figs. 4, 5, 6, 8 and 11. In each case, the light in the laser cavity is confined to substantially the fundamental mode of the multi-mode amplifying optical fiber. In the example of Fig. 1, the tapered leaf fiber 15 operates as an optical guide to confine the light to substantially the fundamental mode. Figs. 9 and 10 show other mechanisms which may be used as optical guides for this purpose.

ISSUE PRESENTED ON APPEAL

Whether Claims 1-19, 22-50 and 55-58 define subject matter which is obvious under 35 U.S.C. §103 over Fermann et al. (5,627,848) in view of Mears et al. (4,787,927).

GROUPING OF THE CLAIMS

In Applicants' opinion, all of the claims should be grouped together for this appeal.

DISCUSSION OF THE REFERENCES RELIED UPON BY THE EXAMINER

THE FERMANN REFERENCE

The Fermann patent (U.S. 5,627,848) discloses a mode-locked fiber laser using a single mode optical fiber. In this respect, it discloses many of the elements of the claims in the present application. It does not, however, disclose the use of a multi-mode fiber, nor does it disclose

confining the light within the multi-mode fiber to preferentially the fundamental mode of the multi-mode fiber.

THE MEARS REFERENCE

The Mears et al. Patent (U.S. 4,787,925 discloses a method of making a preform for drawing doped optical fibers. More specifically, at Col. 3, lines 24 through 55, this patent discloses an embodiment of the invention for fabricating doped multi-mode optical fibbers. Moreover, the reference at Col 1, Lines 12-5 states that doped fibers made according to the invention are useful in manufacturing lasers. No description is provided regarding the form of laser contemplated.

ARGUMENT

Every apparatus claim pending here (Claims 1-50, 58) includes as one element a "multi-mode optical fiber" doped with a gain medium. Every method claim pending here (Claims 55-57) includes as one step "amplifying said light energy within said cavity in a multi-mode fiber." The Examiner states that

> "Fermann et al. Disclose a laser for generating ultra-short optical pulses (Fig. 1, 4-8), comprising: a cavity which repeatedly passes light energy along a cavity axis; a length of multi-mode optical fiber (See Fig. 1, Character 101) doped with a gain medium and positioned along said cavity axis; a pump (see Fig. 1, Character 103) for exciting said gain medium, the multi-mode optical fiber doped with a gain medium and positioned along said cavity axis (see Fig. 1, Character 104."

The cited Fermann reference, however, does not disclose multi-mode fiber. Rather, that reference discloses double-clad single-mode fiber, which is used to permit pumping by a diode laser array. This type of fiber is specifically described in the background section of the cited reference as follows:

> "To minimize cost, modelocked fiber lasers also should employ diode laser arrays. Indeed, it has been long known that continuous wave fiber lasers may be pumped by diode laser arrays when a doubleclad structure is employed in the fiber design. See, e.g., U.S. Pat. No. 4,815,079 to Snitzer et al. According to Snitzer et al., the fiber is designed to have two claddings, wherein the outer cladding has a low refractive index and the inner cladding has a significantly higher refractive index, giving a typical numerical aperture for light capture by the inner cladding between 0.20 and 0.60. The fiber core then has an even higher refractive index and is placed inside the inner cladding, such that the core location is significantly offset from the center of the inner cladding.

> "Snitzer et al. alternatively disclose the inner cladding as having a nearly rectangular shape. Both of these designs ensure that any light launched into the inner cladding crosses over the fiber core as often as possible, so that the light may be efficiently absorbed when the fiber core is doped with a rare-earth gain material. **The fiber core may then be designed to be single mode, and, as a result, a single-mode laser signal output may be obtained when the fiber is placed into a resonator**. Note, however, that perfectly acceptable performance from double-clad fibers having a centro-symmetric fiber structure, i.e., a fiber core placed in the center of the inner cladding, was recently demonstrated. H. Zelmer, U. Williamkowski, A Tunnerman and H. Welling, "High-power cw neodymium-doped double-clad fiber lasers", CLEO 95, paper CMB4. Such pumping schemes were previously predicted in U.S. Pat. No. 3,808,549 to Maurer. **The fiber design can then be reduced to that of a standard single-mode fiber with a low-index coating (such as silicone rubber)**, which, in fact, was the industry standard for fiber fabrication before the advent of acrylate coatings."

U.S. Patent 5,627,848 at Col. 2, Ln. 18-51, emphasis added.

Please note that the fiber described in this portion of the background section is precisely the fiber that is described in the description of the preferred embodiment:

> "One preferable configuration of the fiber 101 includes Er^{3+} and Yb^{3+} doping levels of 800 ppm and 8000 ppm, respectively, in a phosphoaluminosilicate glass host. The core diameter of the fiber 101 is 6μm, with a numerical aperture (NA) of 0.16. The inner cladding has a diameter of 100 μm and is coated with silicon rubber to give the inner cladding an effective NA of 0.4"

U.S. Patent 5,627,848 at Col. 4, Ln. 20-26.

Some confusion may have been introduced by the fact that the reference refers to a mode stripper 104 (see, for example, Col. 4 at ln. 57 and following). This mode stripper, however, is used to remove **cladding modes,** not core modes (see Col. 4, ln. 61-62), and does not suggest that the fiber itself is not a single mode fiber.

This distinction, is supported by the dictionary definitions which are attached to this amendment as Exhibit A. This exhibit was introduced into the file in the amendment filed February 16, 2001. Exhibit A includes copies from the "Fiber Optics Standard Dictionary, pages 614-615 (providing a definition for "multimode optical fiber") and pages 928-929 (providing a definition for "single-mode optical fiber"). The Board will note that these terms refer to the number of "bound" modes, also known as core modes, which the fiber will support. As can be seen from these definitions, in this art, "multi-mode optical fiber" refers to a fiber capable of

supporting multiple bound modes. Because the cited reference only refers to multiple cladding modes, and specifically refers to the fiber itself as "single mode," Applicant believes that the rejection of the pending claims is not supported.

A definition of whether a fiber is multi-mode or single mode is provided in the specification of this case at page 9, lines 8-10: "Typically a fiber is considered multi-mode when the V-value exceeds 2.41...". As described at Col. 4, lines 20-40 of the Fermann reference, the fiber described in the Fermann reference has a core diameter of 6μm and a numerical aperture (NA) of 0.16, while the signal has a wavelength of 1.56μm. Applicant has attached as Exhibit B a copy of U.S. Patent 6,496,301 which includes at Col. 6, Ln. 2 the classic formula for calculating the V-number of fiber: V=(.pi.d_{core} NA)/.lambda., where .lambda. is the wavelength in free space. In this case, pi=3.1416; d_{core} =6μm; NA=0.16 and lambda=1.56μm. Thus, the above formula yields a V-number for the Fermann fiber of 1.93. Since 1.93 is clearly less than 2.41, using the definition in the present application, the Fermann fiber is not multi-mode fiber.

Moreover, the Fermann reference simply makes no suggestion that a multi-mode fiber might be used for a mode-locked pulse laser.

Additionally, the apparatus claims require either "an optical guide positioned on said cavity axis which confines the light amplified by said multi-mode optical fiber to preferentially the fundamental mode of said multi-mode optical fiber" or "means for confining the optical energy amplified by said multi-mode optical fiber to substantially the fundamental mode of said multi-mode optical fiber." Similarly, all of the method claims include a step of "confining said light energy within said laser cavity substantially to the fundamental mode of said multi-mode fiber". No such element or step is suggested by Fermann.

The Examiner attempts to supply this last element by the combination of the Mears patent, stating"

> "The Fermann discloses the claimed invention except for an optical guide positioned on cavity axis which confines the light amplified by said multi-mode optical fiber to preferentially the fundamental mode of said multi-mode fiber, the multi-mode fiber and multi mode filter fiber are tapered at said fusion spliced, and the pump is couple to said multi-mode fiber along said cavity axis. It would have been obvious at the time of applicant's invention, to combine Mears et al of teaching a multi-mode optical fiber doped with a gain medium and positioned along said cavity axis with a laser for

> generating ultra-short optical pulse because if the optical communications system employs multi-mode fiber, each of the different modes will have a different group velocity, thus modulated signals, i.e. pulses of light passing down the multi-mode optical fiber, which are made up of a number of different modes of the waveguide will experience a different group delay from each of their modes. This causes a pulse formed from more than one mode to spread out as it propagates, and is called intermodal dispersion. Once consecutive pulses have spread out so that they are no longer distinguishable, one from the other, the information transmission limit of the optical communications system has been reached. This limit is expressed as a bandwidth distance product since it will be reached at a higher bit rate for a shorter optical communications link. Intermodal dispersion between the modes of multi-mode fibers is one of the reasons why modern optical communications systems have moved to the use of single mode optical fiber which, since it only supports one optical mode, does not suffer from intermodal dispersion. ..."

It is not clear what this statement means. What is clear is that Mears does disclose multi-mode fiber and its manufacture, but does not suggest its use in a mode-locked fiber laser. Certainly, there is no suggestion in Mears that the light within a multi-mode fiber might be limited to substantially the fundamental mode of that fiber, or that an optical guide should be used for this purpose. Simply stated, Mears discloses multi-mode fiber, and nothing more.

In summary, Fermann fails to disclose multi-mode fiber and also fails to disclose the limitation of light to the fundamental mode of that fiber. The Examiner even acknowledges in the rejection the latter deficiency. Mears does nothing to suggest that light within the multi-mode fiber laser be limited substantially to the fundamental mode of the multi-mode fiber.

Appl. No. : **09/785,944**
Filed : **February 16, 2001**

REQUEST FOR ORAL HEARING

Applicant hereby requests an Oral Hearing in this Appeal.

CONCLUSION

Applicants submit that the claims of this application are allowable.

Respectfully submitted,

KNOBBE, MARTENS, OLSON & BEAR, LLP

Dated: 1/16/04

By: ______________________

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APPENDIX

CLAIMS ON APPEAL

1. (Original) A laser for generating ultra-short optical pulses, comprising:

a cavity which repeatedly passes light energy along a cavity axis;

a length of multi-mode optical fiber doped with a gain medium and positioned along said cavity axis;

a pump for exciting said gain medium;

a mode locking mechanism positioned on said cavity axis; and

an optical guide positioned on said cavity axis which confines the light amplified by said multi-mode optical fiber to preferentially the fundamental mode of said multi-mode optical fiber.

2. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said mode locking mechanism comprises a passive mode locking element.

3. (Original) A laser for generating ultra-short optical pulses as defined in Claim 2 wherein said passive mode locking element comprises a saturable absorber.

4. (Original) A laser for generating ultra-short optical pulses as defined in Claim 3 wherein said saturable absorber comprises InGaAsP.

5. (Original) A laser for generating ultra-short optical pulses as defined in Claim 3 additionally comprising a power limiter for protecting said saturable absorber.

6. (Original) A laser for generating ultra-short optical pulses as defined in Claim 5 wherein said power limiter comprises a two photon absorber.

7. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said optical guide comprises a single-mode mode-filter fiber on said cavity axis.

8. (Original) A laser for generating ultra-short optical pulses as defined in Claim 7 wherein said single-mode mode-filter fiber is fusion spliced onto one end of said multi-mode optical fiber.

9. (Original) A laser for generating ultra-short optical pulses as defined in Claim 8 wherein said multi-mode fiber is tapered at said fusion splice.

10. (Original) A laser for generating ultra-short optical pulses as defined in Claim 8 wherein said single-mode mode-filter fiber is tapered at said fusion splice.

11. (Original) A laser for generating ultra-short optical pulses as defined in Claim 8 wherein both said single-mode mode-filter fiber and said multi-mode fiber are tapered at said fusion splice.

12. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said pump is coupled to said multi-mode fiber along said cavity axis.

13. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said pump is coupled to the side of said multi-mode fiber.

14. (Original) A laser for generating ultra-short optical pulses as defined in Claim 13 additionally comprising an optical coupler for coupling said pump to said multi-mode fiber.

15. (Original) A laser for generating ultra-short optical pulses as defined in Claim 13 additionally comprising a v-groove on said multi-mode optical fiber for coupling said pump to said multi-mode fiber.

16. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 additionally comprising a polarization beam splitter for outputting said ultra-short optical pulses from said laser.

17. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said cavity comprises a pair of reflectors at its opposite ends.

18. (Original) A laser for generating ultra-short optical pulses as defined in Claim 17 wherein one of said pair of reflectors is partially reflecting and provides the output for said cavity.

19. (Original) A laser for generating ultra-short optical pulses as defined in Claim 17 wherein said mode locking mechanism comprises a saturable absorber, and wherein one of said reflectors is formed on a surface of said saturable absorber.

20. (Original) A laser for generating ultra-short optical pulses as defined in Claim 19 wherein said mode locking mechanism additionally comprises a power limiter for protecting said saturable absorber, and wherein said saturable absorber is formed on a surface of said power limiter opposite said one of said reflectors.

21. (Original) A laser for generating ultra-short optical pulses as defined in Claim 20 wherein said power limiter comprises a two-photon absorber.

22. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 additionally comprising a linear phase drift compensator on said cavity axis.

23. (Original) A laser for generating ultra-short optical pulses as defined in Claim 22 wherein said linear phase drift compensator comprises a Faraday rotator.

24. (Original) A laser for generating ultra-short optical pulses as defined in Claim 23 wherein said linear phase drift compensator comprises a pair of Faraday rotators.

25. (Original) A laser for generating ultra-short optical pulses as defined in Claim 22 additionally comprising a linear polarization transformer on said cavity axis.

26. (Original) A laser for generating ultra-short optical pulses as defined in Claim 25 wherein said linear polarization transformer comprises a wave plate.

27. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said mode locking mechanism comprises an active mode locking element.

28. (Original) A laser for generating ultra-short optical pulses as defined in Claim 27 wherein said active mode locking element comprises an optical amplitude modulator.

29. (Original) A laser for generating ultra-short optical pulses as defined in Claim 27 wherein said active mode locking element comprises an optical frequency modulator.

30. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said ultra-short optical pulses preferentially in the fundamental mode of said multi-mode optical fiber have a pulse width below 500 psec.

31. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 additionally comprising an environmental stabilizer on said cavity axis to assure that said cavity remains environmentally stable.

32. (Original) A laser for generating ultra-short optical pulses as defined in Claim 31 wherein said environmental stabilizer comprises a Faraday rotator.

33. (Original) A laser for generating ultra-short optical pulses as defined in Claim 32 wherein said environmental stabilizer comprises a pair of Faraday rotators.

34. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said optical guide comprises an optical fiber doped with an amplifying medium to provide gain guiding.

35. (Original) A laser for generating ultra-short optical pulses as defined in Claim 34 wherein said amplifying medium is concentrated centrally within a fraction of the core diameter of said optical fiber.

36. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said optical guide comprises a single-mode optical fiber on said cavity axis.

37. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said optical guide comprises a mode-filter on said cavity axis.

38. (Original) A laser for generating ultra-short optical pulses as defined in Claim 37 wherein said mode filter excites the fundamental mode of said multi-mode fiber.

39. (Original) A laser for generating ultra-short optical pulses as defined in Claim 38 wherein said mode filter excites the fundamental mode of said multi-mode fiber with an efficiency of at least 90%.

40. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said cavity additionally comprises a positive dispersion element.

41. (Original) A laser for generating ultra-short optical pulses as defined in Claim 40 wherein said positive dispersion element comprises a length of single-mode positive dispersion fiber positioned along said cavity axis.

42. (Original) A laser for generating ultra-short optical pulses as defined in Claim 41 additionally comprising an output coupler for limiting the light energy at said single-mode positive dispersion fiber to less than 10% of the peak power in said cavity.

43. (Original) A laser for generating ultra-short optical pulses as defined in Claim 42 additionally comprising a frequency converter for compressing pulses generated by said cavity.

44. (Original) A laser for generating ultra-short optical pulses as defined in Claim 43 wherein said frequency converter comprises a frequency doubler.

45. (Original) A laser for generating ultra-short optical pulses as defined in Claim 44 wherein said frequency doubler comprises chirped periodically poled $LiNbO_3$.

46. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said multi-mode fiber includes a core, and wherein said gain medium in said multi-mode optical fiber is concentrated centrally within the core of said multi-mode fiber.

47. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said multi-mode optical fiber is polarization-maintaining.

48. (Original) A laser for generating ultra-short optical pulses as defined in Claim 47 wherein said polarization-maintaining multi-mode fiber has an elliptical core.

49. (Original) A laser for generating ultra-short optical pulses as defined in Claim 47 wherein said polarization maintaining multi-mode fiber comprises stress-producing regions.

50. (Original) A laser for generating ultra-short optical pulses as defined in Claim 1 wherein said cavity additionally comprises a fiber grating written onto said multi-mode fiber, said grating primarily reflecting the fundamental mode of said multi-mode fiber.

51. (Canceled)

52. (Canceled)

53. (Canceled)

54. (Canceled)

55. (Previously Presented) A method of generating ultra-short optical pulses, comprising:

circulating light energy within a laser cavity;

amplifying said light energy within said laser cavity in a multi-mode fiber; and

confining said light energy within said laser cavity substantially to the fundamental mode of said multi-mode fiber.

56. (Original) A method of generating ultra-short optical pulses as defined in Claim 55 additionally comprising mode locking said light energy.

57. (Original) A method of generating ultra-short optical pulses as defined in Claim 55 wherein said confining comprises mode filtering said light energy.

58. (Original) A mode-locked laser for generating high power ultra-short optical pulses, comprising:

A multi-mode optical fiber doped with gain material for amplifying optical energy;

means for pumping said optical fiber; and

means for confining the optical energy amplified by said multi-mode optical fiber to substantially the fundamental mode of said multi-mode optical fiber.

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transmission system, interface, optical interface, optical signal, propagation medium, radio, signal, sound signal, telegraph, telephone, transmission system, video, voice.**

multimegabit data service: A data service that provides a data signaling rate (DSR) that is over 1 Mb · s^{-1} (Mb/s, megabits per second). *Note:* A fiber optic link has the capability to provide multimegabit data services. *See* **switched multimegabit data service.** *See also* **data signaling rate, fiber optic link, telecommunications service.**

multimeter: A test instrument that (a) is used for measuring voltages, currents, and resistances that may lie within a number of different ranges, (b) has a range selection capability to obtain measurement precision, and (c) must be operated with caution so as not to allow the indicator to go off scale. A measurement should be made starting with the scale that measures the largest unit. *Note:* A lightwave multimeter manufactured by the Hewlett-Packard Company that has two slots for plug-in modules with sensitivities from −70 dBm to −110 dBm and a wavelength range from 450 nm to 1700 nm (0.45 μm to 1.7 μm). *Synonyms* **volt-ohm meter, volt-ohm milliammeter.** *See* **digital multimeter, electronic multimeter, optical multimeter.** *See also* **current, precision, range, scale, voltage.** *Refer to* **Fig. L-8.**

multimode: In an electromagnetic wave propagating in a waveguide, such as a lightwave propagating in an optical fiber, pertaining to (a) the existence of two or more modes in the wave or (b) the capability of the waveguide to support two or more modes. *See also* **electromagnetic wave, lightwave, mode, optical fiber, propagation, single mode, waveguide.** *Refer to* **Figs. O-1, T-6.**

multimode dispersion: 1. *Synonym* **multimode distortion. 2.** *See* **optical multimode dispersion.**

multimode distortion: In an optical waveguide, such as an optical fiber, a slab dielectric waveguide, or optical integrated circuit (OIC), the distortion that (a) results from differential mode delay, (b) is a result of the spread in time of a pulse because the velocity of propagation is not the same for all the modes in an optical pulse, i.e., optical signal, and (c) is not a result of dispersive mechanisms, i.e., is not a form of dispersion, such as waveguide dispersion, profile dispersion, or material dispersion. *Note 1:* Multimode distortion in multimode step-index optical fibers may be compared to multipath propagation of radio signals. The direct signal is distorted by the arrival of the reflected signals a moment later. In a step-index optical fiber, rays taking more direct paths through the fiber core, i.e., those undergoing fewer reflections at the core-cladding boundary, traverse the length of the fiber sooner than those rays that undergo more reflections, resulting in signal distortion at the end of the fiber. *Note 2:* Multimode distortion limits the bandwidth of a given multimode optical fiber. A typical step index optical fiber with a 50-μm (micron) core would be limited to about 20 MHz (megahertz) for a 1-km (kilometer) length, i.e., a bandwidth · distance factor of 20 MHz · km. *Note 3:* Multimode distortion may be considerably reduced, but not completely eliminated, by the use of a core having a graded refractive index profile. The bandwidth · distance factor of a typical off-the-shelf graded index multimode optical fiber having a 50-μm (micron) core may be over 1 GHz · km (gigahertz · kilometer), with over 10 GHz · km fibers having been produced. *Note 4:* Because of its similarity to dispersion in its effect on optical signals, multimode distortion is sometimes incorrectly referred to as "intermodal dispersion," "modal dispersion," or "multimode dispersion." Such usage is incorrect because multimode distortion is not truly a dispersive effect. Dispersion is a wavelength-dependent phenomenon, particularly because of the spectral width of a pulse, whereas multimode distortion may occur to a single wavelength. *Synonyms* **intermodal distortion, modal distortion, multimode dispersion.** *See also* **bandwidth · distance factor, cladding, coherence area, coherence length, coherence time, core, differential mode delay, distortion, distortion-limited operation, fiber optics, graded refractive index, material dispersion, mode, multimode optical fiber, multipath, optical pulse, optical signal, optical waveguide, profile dispersion, propagation, spectral width, step index optical fiber, waveguide dispersion, wavelength.**

multimode facility: In communications systems, a facility that is capable of handling more than one transmission mode, such as telephone, telegraph, radio, and facsimile transmission. *See also* **facility, facsimile, radio, telegraph, telephone, transmission mode.**

multimode fiber: *Synonym* **multimode optical fiber.**

multimode group delay: *Synonym* **differential mode delay.**

multimode group delay spread: In an electromagnetic wave propagating in a waveguide, such as an optical pulse propagating in an optical fiber, the variation in group delay time, caused by differences in group velocity, among bound propagating modes even at a single frequency. *Note:* The differences in arrival times of the leading and trailing edges of a pulse at the end of the waveguide, as compared to the sending end, is caused by the different propagation delays of the different modes. The modes can be considered as different opti-

cal paths of different optical path lengths. In an optical fiber, it is possible for photons or waves that propagate along the optical fiber axis of the core to arrive at the end sooner than those that follow a helical path through the core, thus causing the pulse duration at the end of the fiber to be increased. If the pulse duration is too great, intersymbol interference, i.e., an overlapping of consecutive pulses, will occur. The duration of the received pulse can be reduced if the refractive index profile of the core is arranged so that light rays taking a helical path along the outer edges of the core propagate through a lower-refractive-index material, hence travel faster in the longer path than axial rays propagating along the optical axis, or in a helical path closer to the axis of the core, in the higher refractive index material, so that they arrive at the end of the fiber at the same time. Actual propagation delay is of little consequence, as long as all rays of a given pulse arrive at the end of the fiber at the same time. Zero-dispersion optical fibers are being made. *Synonym* **differential mode delay.** *See also* **bound mode, core, electromagnetic wave, group delay time, group velocity, intersymbol interference, leading edge, mode, optical fiber, optical fiber axis, optical path length, optical pulse, path, photon, propagation, propagation delay, pulse duration, ray, refractive index profile, trailing edge, wave, zero dispersion, zero-dispersion optical fiber.**

multimode laser: A laser that emits radiation containing two or more modes, i.e., two or more different central wavelengths. *See also* **central wavelength, laser, multiline laser, radiation.**

multimode operation: In analog systems, the use of a common circuit or a single propagation medium for both analog and digital data, such as voice, binary coded data, facsimile, and international Morse code all on one circuit though not necessarily at the same time. *Note:* Simultaneous transmission in more than one transmission mode at the same time can be accomplished using multiplexing techniques. Fiber optic nets, fiber optic links, and fiber optic loops can support multimode operation. *See also* **analog data, circuit, digital data, facsimile, fiber optic link, fiber optic loop, fiber optic net, international Morse code, mode, multiplexing, propagation medium, transmission mode, voice.**

multimode optical fiber: An optical fiber that supports the propagation of more than one bound mode at a given operating wavelength. *Note 1:* A multimode optical fiber may be either a graded index (GI) optical fiber or a step index (SI) optical fiber. *Note 2:* The number of modes that an optical fiber will support depends on the core diameter, the numerical aperture (NA), and the wavelength. *Synonym* **multimode fiber.** *See also* **bound mode, cladding mode, core, core diameter, coupled modes, fiber optics, graded index optical fiber, modal distribution, modal n ise, mode, mode scrambler, mode volume, numerical aperture, optical fiber, single-mode optical fiber, step index optical fiber, wavelength.** *Refer to* **Figs. A-6, L-11, R-7.** *Refer to* **Appendix B, Tables 2, 4.**

multimode waveguide: A waveguide that can support more than one mode. *Note:* Because different wavelengths constitute different modes and the number of modes is also dependent on the numerical aperture (NA) and the core diameter, a given "multimode" waveguide might support only one mode and therefore could be called a single-mode waveguide if the operating wavelength is long enough, and conversely, a given "single-mode waveguide" might support several modes and therefore could be called a multimode waveguide if the operating wavelength is short enough. *See also* **core, core diameter, mode, numerical aperture, single-mode waveguide, wavelength.**

multinode network: A communications network, such as a fiber optic net, in which users may be interconnected through more than one node. *See also* **fiber optic net, network, node.**

multipaired cable: A paired cable that has two or more pairs of electrical conductors, such as two or more twisted pairs. *See also* **cable, conductor, fiber optic cable, hybrid cable, paired cable, twisted pair.**

multipath: 1. For lightwaves in dielectric waveguides, pertaining to the different paths taken by the various modes in lightwaves propagating in the waveguide. *Note:* Causes of multipath in optical fibers include refractive index and entrance condition variations. **2.** The propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. *Note 1:* For radio, video, and microwave transmissions, causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from terrestrial objects, such as mountains and buildings. *Note 2:* Multipath can cause constructive interference, phase shifting, and destructive interference. *Note 3:* In facsimile and television transmission, multipath causes jitter and ghost images. *See also* **antenna, capture effect, constructive interference, destructive interference, dielectric waveguide, entrance condition, facsimile, ghost image, ionosphere, jitter, lightwave, mode, object, phase, phase shift, propagation, Rayleigh fading, reflection, refraction, refractive index, television, waveguide.**

multipath fading: In the propagation of electromagnetic waves, including (a) radio waves in free space and the atmosphere and (b) lightwaves in dielectric waveguides, such as optical fibers, slab dielectric wave-

single harmonic distortion: In a signal, the ratio of (a) the power of a given harmonic, such as the second, third, or fourth harmonic, to (b) the power of the fundamental frequency, i.e., the first harmonic. *Note:* Single harmonic distortion is measured at the output of a device under specified conditions and usually is expressed in dB. *See also* **distortion, frequency, fundamental frequency, harmonic distortion, signal, total harmonic distortion.**

single heterojunction: In a laser diode, a junction that (a) performs two energy level shifts and two refractive index shifts and (b) provides increased confinement of radiation direction, improved control of radiative recombination, and reduced nonradiative (thermal) recombination. *See also* **energy level, junction, laser diode, nonradiative recombination, radiation, radiative recombination.**

single inline package: An integrated circuit package that (a) has a rectangular housing, (b) has one row of pins on a side, and (c) is compatible with standard integrated circuit sockets. *Common abbreviation:* **SIP.** *Note:* An example of a dual inline package (DIP) is a microcircuit package with one row of seven vertical leads that is specially designed for mounting on a printed circuit board. The SIP is used to contain control circuits for controlling fiber optic links and fiber optic nets. *See also* **circuit, dual inline package, fiber optic link, fiber optic net, integrated circuit, large-scale integrated circuit, optical integrated circuit, single inline package switch.**

single lens: A lens composed of only one piece of optical material, such as glass or plastic. *See also* **compound lens, glass, optical glass, optical plastic.**

single mode: 1. In an electromagnetic wave propagating in a waveguide, such as a lightwave propagating in an optical fiber, pertaining to (a) the existence of one and only one mode in the wave or (b) the capability of the waveguide to support one and only one. **2.** In an electromagnetic wave, such as a lightwave or radio wave, propagating in a waveguide, such as an optical fiber, a hollow or dielectric-filled rectangular metallic waveguide, a slab dielectric waveguide, or an optical integrated circuit (OIC), pertaining to an operating condition in which only one propagation mode, i.e., a beam of only one wavelength, is supported by the waveguide because (a) the wavelength is at the cutoff wavelength, (b) shorter wavelengths could be supported but they are not in the incident wave, i.e., in the wave inserted into the guide, and (c) longer wavelengths cannot be supported even if they are in the incident waves, i.e., they do not fit in the cross section of the guide. *Note 1:* The concept of single mode is also applicable to sound waves in a length of tubing and to vibrations in material media. *Note 2:* An optical fiber designated as a single-mode fiber can support more than one mode by inserting lightwaves of shorter wavelength. Thus, for single-mode operation of a given fiber, the operating wavelength must be specified. *Note 3:* The single mode usually is the lowest order bound mode, consisting of a pair of orthogonally polarized electric and magnetic fields. *See also* **cutoff wavelength, electric field, electromagnetic wave, incident, lightwave, lowest order mode, low-order mode, magnetic field, mode, multimode optical fiber, operating wavelength, optical fiber, optical integrated circuit, orthogonal, polarization, polarized mode, propagation, propagation medium, radio wave, single-mode optical fiber, slab dielectric waveguide, waveguide.** *Refer to* **Figs. O-1, S-20, T-6.**

single-mode fiber: *Synonym* **single-mode optical fiber.**

single-mode launching: The insertion of an electromagnetic wave into a waveguide in such a manner that (a) only one propagation mode is coupled into, and hence transmitted, by the guide, (b) various parameters, such as incidence angle, beam diameter, skew ray angle, and source to waveguide longitudinal displacement are controlled, and (c) propagation of the mode depends on waveguide dimensions, the wavelength of the inserted waves, and refractive indices of the material constituting the guide. *See also* **coupling, electromagnetic wave, incidence angle, mode, parameter, propagation, refractive index, skew ray, transmission, waveguide.**

single-mode optical fiber: An optical fiber in which only one bound mode, i.e., the lowest order bound mode, can propagate at a given wavelength, numerical aperture, and core radius. *Note 1:* The lowest order bound mode may be a pair of orthogonally polarized electric and magnetic fields. *Note 2:* To support one mode, the core radius must be less than twice the wavelength of the source of radiation and the numerical aperture must be adjusted accordingly. *Note 3:* In step index optical fibers, single-mode operation occurs when the normalized frequency, V, is less than 2.405. For power law profiles, single-mode operation occurs for a normalized frequency, V, less than approximately $2.405[(g + 2)/g]^{1/2}$, where g is the profile parameter. *Note 4:* If appropriate conditions are met, the orthogonal polarizations will not be associated with degenerate modes. *Synonyms* **monomode fiber, monomode optical fiber, single-mode fiber.** *See* **dispersion-unshifted single-mode optical fiber.** *See also* **bound mode, core, core diameter, mode, multimode optical fiber, normalized frequency, numerical aperture, operating**

mode, optical fiber, profile parameter, radiation, source, step index optical fiber. *Refer to* **Figs. E-1, L-11, M-3, R-7, S-9.**

single-mode optical waveguide: An optical waveguide that is capable of supporting the propagation of only one mode at a given wavelength. *Note:* An optical waveguide designed to operate in single mode at a given wavelength may support more than one mode if operated at shorter wavelengths. *See also* **mode, multimode, operating wavelength, optical waveguide, propagation, single mode, single-mode optical fiber, wavelength.**

single-mode waveguide: 1. A waveguide that can support only one mode. *Note:* Because different wavelengths constitute different modes and the number of modes is also dependent on the numerical aperture (NA) and the core diameter, a given multimode waveguide might support only one mode in a given wavelength range and therefore could be called a "single-mode waveguide" if the operating wavelength is long enough, and conversely, a given single-mode waveguide might support several modes and therefore could be called a multimode waveguide if the operating wavelength is short enough. **2.** A waveguide in which only one bound mode, i.e., the lowest order bound mode, can propagate at a given wavelength, numerical aperture, and cross-sectional dimension. *Note 1:* The lowest order bound mode may be a pair of orthogonally polarized electric and magnetic fields. *Note 2:* To support one mode, the cross-sectional dimension must be less than twice the wavelength of the source of radiation and the numerical aperture must be adjusted accordingly. *Note 3:* If appropriate conditions are met, the orthogonal polarizations will not be associated with degenerate modes. *Synonym* **monomode waveguide.** *See also* **bound mode, core, electric field, magnetic field, mode, multimode waveguide, numerical aperture, operating mode, orthogonal, polarization, radiation, range, single-mode optical fiber, source, waveguide, wavelength.**

single-node network: *See* **network topology.**

single optical fiber: An optical fiber that is optically isolated from other optical fibers but may be combined with other optical fibers to form fiber optic cables, aligned bundles, unaligned bundles, and fiber optic faceplates. *See also* **aligned bundle, fiber optic cable, fiber optic faceplate, optical fiber.**

single precedence message: A message in which (a) the same precedence is applicable to all addressees, i.e., to both action addressees and information addressees, and (b) only one precedence designator is needed. *See also* **dual precedence message, message, precedence, precedence designator.**

single sideband: Pertaining to amplitude modulation that (a) primarily is used in carrier telephony and high frequency (HF) radio to increase transmission efficiency, i.e., power efficiency, (b) is used to increase electromagnetic spectrum utilization in terms of the total number of channels available in a given bandwidth, (c) uses only one sideband for transmission while the other sideband and the carrier is suppressed, and (d) although proposed for the uplink and downlink of satellite systems, its use in satellite systems has been limited. *Common abbreviations:* **SS, SSB.** *See also* **amplitude modulation, bandwidth, carrier, channel, downlink, electromagnetic spectrum, satellite communications system, sideband, suppressed carrier, transmission efficiency, uplink.**

single sideband emission: An amplitude-modulated emission with only one sideband. *Common abbreviation:* **SSB emission.** *See also* **amplitude modulation, carrier, double sideband reduced carrier transmission, double sideband suppressed carrier transmission, double sideband transmission, emission, full carrier single sideband emission, reduced carrier single sideband emission, sideband, sideband transmission, suppressed carrier single sideband emission.**

single sideband equipment reference level: The power of one of two equal tones that, when used together to modulate a transmitter, cause it to develop its full rated peak power output. *Common abbreviation:* **SSB equipment reference level.** *See also* **level, peak power output, rated power output, reference, reference circuit, reference level, sideband transmission, transmitter.**

single sideband noise power ratio: The ratio of (a) the output power, measured with a notch in, to (b) the output power, measured with the notch out. *Note 1:* Measurements are made in which (a) notched noise is used, (b) power is in the notch bandwidth, and (c) power is measured at the output of the device for which the single sideband (SSB) noise power ratio is being determined. *Note 2:* The input power must be sufficient to maintain a constant total system mean noise power output. *See also* **noise, notch, notched noise.**

single sideband suppressed carrier (SSB-SC) transmission: Single sideband transmission in which (a) the carrier is suppressed and (b) the carrier power level is suppressed so that it is insufficient for signal demodulation. *Common abbreviation:* **SSB-SC transmission.** *See also* **carrier, demodulation, power level, single sideband transmission.**

single sideband transmission: Sideband transmission in which (a) only one sideband is transmitted and (b) the